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ASEP

APPENDIX 1-B

GUIDELINES AND IMPLEMENTING RULES ON EARTHQUAKE RECORDING INSTRUMENTATION FOR BUILDINGS

I. INTRODUCTION

Technology on building instrumentation for seismic monitoring has improved tremendously in the past decade. The purpose of this Guidelines and Implementing Rules on Earthquake Recording Instrumentation for Buildings is to provide information on the specifications and uses of earthquake recording instruments or buildings as provided in Section 105.2 of the National Structural Code of the Philippines 2010 Volume 1, Sixth Edition [NSCP 2010].

The Guidelines and Implementing Rules on Earthquake Recording Instrumentation for Buildings provide earthquake instrumentation schemes for certain buildings to record building response during major seismic events for subsequent analysis. Adequate analysis of building response during earthquake is an important parameter in building safety evaluation in the confirmation and resumption of operations.

Installation of earthquake recording instruments first appeared in the National Structural Code of the Philippines 1992 Edition. At that period, structural engineers were mostly interested in the strength design capacity of the buildings based on seismic parameters provided in the Uniform Building Code (UBC) of the United States, a referral standard of the NSCP. This provision in the 1992 NSCP, however, was not enforced. Code developers started to recognize the importance of not only strength but serviceability in buildings as well. The experiences from the 1994 Northridge Earthquake in the US and the 1995 Kobe Earthquake in Japan gave credence to these considerations.

The NSCP 2010 states that *“Unless waived by the building official, every building in Seismic Zone 4 over fifty (50) meters in height shall be provided with not less than three (3) approved recording accelerograph. The accelerograph shall be interconnected for common start and common timing.”* Due to recent earthquakes and proliferation of high-rise buildings, the Philippines needs to have its own earthquake records for validating the seismic design parameters used, in order to support earthquake disaster mitigation / remedial efforts; thus, there is the need to implement the requirements for the earthquake recording instrumentation. Until such time that considerable sets of

adequate earthquake records have been obtained for various types of buildings or relevant provisions in the NSCP have been amended, the waiver stated above is temporarily suspended and buildings indicated in Table 1 shall be provided with earthquake recording instruments.

ASEP therefore deemed it necessary to improve our understanding of the building response based on real seismic event from local earthquake generators by promoting earthquake recording instrumentation for buildings as the NSCP provision was reiterated in the 2001 and 2010 Editions. Due to more recent developments in building instrumentation technology, a number of instrumentations are available to obtain the building response, and satisfy and comply with the objective of the NSCP Section 105 provisions. Hence, the requirement for three (3) accelerographs is further enhanced and modified to consider the latest and economical building instruments, thus, the combination or combinations of accelerographs, accelerometers, velocity meters and data loggers are considered. To measure building response due to long period earthquakes and distant sources normally critical to tall buildings, the addition of velocimeters is necessary.

To further address the disaster management effort in the country, essential facilities such as hospitals and some government buildings, which are important facilities in disaster response, are recommended to be instrumented. In addition, with this new provision, building response from low-rise structures can be obtained to determine building behavior due to near source or short period earthquakes.

III. OBJECTIVES OF THESE GUIDELINES

Section 102 of the National Building Code of the Philippines (PD 1096) states that *“It is hereby declared to be the policy of the State to safeguard life, health, property, and public welfare, consistent with the principles of sound environmental management and control; and to this end, make it the purpose of this Code to provide for all buildings and structures, a framework of minimum standards and requirements to regulate and control their location, site, design, quality of materials, construction, use, occupancy, and maintenance.”*

In conformance thereto and as provided in the NSCP 2010, these Guidelines and Implementing Rules on Earthquake Recording Instrumentation for Buildings is developed to improve the understanding of the actual dynamic behavior of buildings under earthquake loading and confirm the design according to the NSCP. The recorded data can be used to improve the structural code thereby reducing loss of lives and limbs as well as properties during future damaging earthquakes. The response data from several buildings in a particular area or several areas will also be used as basis for the government’s earthquake disaster mitigation/remedial and rehabilitation strategies including its emergency response and relief operations programs. The instruments may also be used to set off alarms at specified intensity levels. They may also be used to trigger automatic switching off utilities such as gas lines, electric power lines and elevators as may be prudent in case of high intensity earthquake. The recorded data are important parameters for building safety re-evaluation and resumption of operations including post-earthquake evaluation of buildings.

IV. DEFINITION OF TERMS

ACCELEROGRAPH are accelerograph records the acceleration of particles on the surface of the earth as a function of time, which is called an accelerogram. The accelerograph generally records three mutually perpendicular components of motion in the vertical and two orthogonal horizontal directions.

ACCELERATION is the rate at which the velocity of a particle changes with time.

ACCELEROMETER is an instrument used to measure acceleration in the vertical and two orthogonal horizontal directions. An accelerometer has no built-in data recording capacity and is attached to a multi-channel data logger or an accelerograph to record measured acceleration.

ACCREDITED STRUCTURAL ENGINEER (ASE) is a civil engineer with special qualifications to practice structural engineering with special training in earthquake engineering and certified by ASEP.

ACTIONS (GROUND MOTION) is a general term including all aspects of ground motion, namely acceleration, velocity, or displacement from an earthquake or other energy source.

BANDWIDTH is the frequency range that the sensor operates, measured in hertz. (Hz)

CHANNEL is a path along which information (as data or voice) in the form of electrical signal, passes; a band of frequencies of sufficient width for a single radio or television communication.

CLUSTERED BUILDINGS is a group of buildings built close together on a sizable tract of land in order to preserve open spaces larger than the individual yard for common recreation.

DAMPING is the energy dissipation properties of a material or system under cyclic stress.

DATA LOGGER is a data logger is an electronic device that records data over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors.

DISPLACEMENT is the measured distance travelled by a particle from an initial position.

ENVIRONMENT is the aggregate of surrounding things, conditions, or influences that may affect the operability of an instrumentation device such as accelerometer, velocimeter, etc.

ERI. Earthquake Recording Instrumentations.

FFT. Fast Fourier Transform (FFT) is a numerical algorithm to compute the discrete Fourier transform (DFT) and its inverse. Fourier analysis converts time to frequency and vice versa; an FFT rapidly computes such transformations by factorizing the DFT matrix into a product of sparse factors.

GALS is the unit measure of acceleration equivalent to $(1/1000)*g$. Note that 1000 gals = 1g.

g is acceleration due to gravity equals to 9.81 m/s^2 or 32.2 ft/s^2 .

INTENSITY is a number (written as a Roman numeral) describing the severity of an earthquake in terms of its effects on the earth's surface and on humans and their structures.

INTENSITY METER is an intensity meter records and stores the various data that are associated with the earthquake and that it can notify those data to host system as it equips data communication function. In addition, it makes the "Earthquake Early Warning System" workable with creating a system network by making use of optional "earthquake early detecting function."

IP67. The Ingress Protection rating system is a classification system showing the degrees of protection of the instrumentation device from solid objects and liquids. The first number refers to the protection against solid objects, normally dust. If the first number is 0, there is no protection provided. A number 5 refers to limited protection against dust. The number 6 is for total protection against dust. The second number of the IP rating system refers to protection against liquids. A "0" indicates no protection, while a "7" refers to protection against immersion between 15 cm to 1 m for 30 minutes.

NATURAL FREQUENCY is the number of wave cycles per second which a system tends to oscillate in the absence of any driving or damping force.

PEAK GROUND ACCELERATION [PGA] is the maximum ground acceleration at a specific location for the time interval.

PERIOD is the time interval required for one full cycle of a wave.

REFUGE AREA is an area inside a building where people evacuate or assemble during a disaster or emergency i.e. fire, but not for earthquake.

RESPONSE SPECTRUM is a plot of the peak or amplitude of steady-state response (displacement, velocity or acceleration) of a series of oscillators of varying natural frequency that are forced into motion by the same base vibration or shock.

SIR. Seismic Instrumentation Room.

STRONG MOTION is a ground motion of sufficient amplitude to be of interest in evaluating the damage caused by earthquakes or nuclear explosions.

TIME HISTORY is the sequence of values of any time-varying quantity (such as a ground motion measurement) reckoned at a set of [usually] equal time intervals.

VELOCIMETER is an instrument used to measure velocity of a particle.

VELOCITY is a measure of the rate of motion of a particle expressed as the rate of change of its position in a particular direction with time.

V. EARTHQUAKE RECORDING INSTRUMENTATION REQUIREMENTS

The requirements of NSCP Section 105.2 shall apply to all existing buildings listed in Table 1, located in Seismic Zone 4 (entire Philippines except Palawan and Tawi-Tawi), for which certificates of occupancies were issued. Building permits shall only be issued for buildings qualified for seismic instrumentation when site or location of SIR has been indicated or incorporated in the plan.

TABLE 1. EARTHQUAKE RECORDING INSTRUMENTATION REQUIREMENTS		
TYPE AND HEIGHT OF BUILDING	LOCATION	REQUIREMENTS
GOVERNMENT BUILDINGS		
A. Hospitals, schools and other buildings fifty (50) meters high and above	<ol style="list-style-type: none"> 1. Three (3) accelerographs at Ground Floor / Lowest Basement; Middle Floor; and Floor Below Roof, or 2. One (1) accelerograph at Ground Floor / Lowest Basement interphased with two (2) accelerometers at Middle Floor and Floor Below Roof, or 3. Three (3) accelerometers with common data logger at Ground Floor / Lowest Basement; Middle Floor; and Floor Below Roof 	<ol style="list-style-type: none"> 1. Accelerograph for recording waveform and transformed to FFT. 2. Data output to include acceleration response spectra and pseudo acceleration response. 3. With GPS capability. 4. Capability to send data to data center of the government.
B. Hospitals with 50-bed capacity or more and Schools with twenty (20) classrooms or more but not less than three (3) storey high	One (1) accelerograph or one (1) accelerometer connected to a data logger, at Ground Floor / Lowest Basement	
C. Provincial / City / Municipal Halls and Buildings	One (1) accelerograph or one (1) accelerometer connected to a data logger, at Ground Floor Level/Lowest Basement	

TABLE 1. EARTHQUAKE RECORDING INSTRUMENTATION REQUIREMENTS (continued)		
TYPE AND HEIGHT OF BUILDING	LOCATION	REQUIREMENTS
PRIVATE BUILDINGS		
A. Buildings fifty (50) meters high and above	<ol style="list-style-type: none"> 1. Three (3) accelerographs at Ground Floor / Lowest Basement; Middle Floor; and Floor Below Roof, or 2. One (1) accelerograph at Ground Floor / Lowest Basement interphase with two (2) accelerometers at Middle Floor and Floor Below Roof, or 3. Three (3) accelerometers with common data logger at Ground Floor / Lowest Basement; Middle Floor; and Floor Below Roof 	<ol style="list-style-type: none"> 1. Accelerograph for recording waveform and transformed to FFT. 2. Data output to include acceleration response spectra and pseudo acceleration response. 3. For buildings above ninety (90) meters or thirty (30) storeys in height, additional velocity meter at ground floor / lowest basement shall be installed. Output data to include velocity response spectra and pseudo velocity response spectra. Data logger to be part of the system.
B. Hospitals with 50-bed capacity or more and Schools with 20 classrooms or more but not less than three (3) storey high	One (1) accelerograph or one (1) accelerometer connected to a data logger at Ground Floor / Lowest Basement	<ol style="list-style-type: none"> 4. With GPS capability.
C. Commercial Buildings with occupancy of at least one thousand (1,000) persons or gross floor area of at least ten thousand (10,000) square meters	One (1) accelerograph or one (1) accelerometer connected to a data logger at Ground Floor / Lowest Basement	

Table 1 shows the types of buildings required to be installed with earthquake recording instrumentation. The requirements for installation of accelerograph are for buildings located in cities and municipalities within a 200 km radius from a Type A faults as specified in the NSCP 2010 and as indicated from the active fault maps issued by the Philippine Institute of Seismology and Volcanology (PHIVOLCS).

For clustered buildings with completely similar design and construction, it shall have a minimum of eighteen (18) channels with a common data logger. The location of the instruments shall be determined by an Accredited Structural Engineer.

1. *Maintenance.* Earthquake Recording Instruments shall be maintained in proper working condition. The installation, servicing or removal of the instruments shall be done by qualified technical personnel of the supplier whose product complies with the minimum specifications as specified in these Guidelines and Implementing Rules.

Maintenance of the instruments shall be by the owner of the building subject to the monitoring of the Building Official or its designated representative.

2. *Service Period.* The maximum service interval is one (1) year. If the instrument is inoperative at two consecutive service inspections, then a re-inspection and servicing shall be required at a maximum service interval of six (6) months until the instrument is rendered fully operative. When the instrument continuously requires repair for a period of four (4) consecutive years, or inoperative repeatedly for at least three (3) times in a four (4)-year period, the instrument shall be replaced.
3. *Instrumentation of Selected Building.* All owners of existing buildings listed in Table 1 shall provide accessible space for the installation of appropriate earthquake recording instruments. Location of said instruments shall be determined by an Accredited Structural Engineer.

For proposed buildings, the Accredited Structural Engineer shall include the layout, instrument specifications, installation requirements, and location of the instrument in the structural plans submitted for building permit purposes.

The actual installation of the instruments shall be verified by the Building Official.

For existing buildings without ERI, the installation of these instruments shall form part of the requirements of the Annual Certificate of Inspection issued by the Building Official.

For existing buildings with ERI, the building owner shall be required to submit a certification from ASE that the existing ERI conform to these guidelines. If the existing ERI do not conform to these guidelines, the building owner shall upgrade such ERI.

For new buildings, the installation of these instruments shall form part of the requirements for Certificate of Occupancy issued by the Building Official.

4. *Additional Requisite Information of Buildings to be instrumented.* It is necessary to establish a baseline data to make effective use of the records to be collected from the accelerograph(s) installed in the building. The following information are required:
 - As-built blueprints,
 - Structural design calculations,
 - Dynamic analysis (mode shapes and frequencies) as used in the design calculations, if available, forced-vibration test results, and ambient-vibration test results, and
 - Comprehensive subsurface soil exploration and investigation report.

VI. DATA PROCESSING

Modern strong motion instruments have capabilities to store and transmit digital data through telecommunications links and other media, including the internet.

1. The data from digital recordings are passed through a correction algorithm that applies a high-frequency filter (50 Hz typical: 1 Hz=1 cycle per second). Plots of the corrected acceleration, velocity, and displacements for each channel of recording are prepared.
2. Response spectra are calculated for periods up to about half of the long-period limit. Linear plots of relative-acceleration response spectra and plots of pseudo-acceleration response are prepared if specified to the instrument supplier.
3. Fourier amplitude spectra, calculated by Fast Fourier Transform (FFT), are presented on linear axes and log-log axes. These sets of processed data are then provided to the user for evaluation, assessment of facilities and structures, and research.

VII. STANDARD SPECIFICATIONS / REQUIREMENTS FOR EARTHQUAKE RECORDING INSTRUMENTS

1. The following are the minimum specifications for Earthquake Recording Instruments to be used for buildings listed in Table 1.
 - A. Accelerographs/Accelerometers:
 - Minimum design life: Ten (10) years and should be demonstrated and certified to have a 40,000-hour mean time (minimum) between failures.
 - Minimum of three (3) components - Vertical, Longitudinal and Transverse
 - Natural frequency: Above 50 Hz.
 - Damping: Approximately 60 to 70 percent critical.
 - Sensitivity: ± 2000 gals or $\pm 2g$ (full scale/V)
 - Bandwidth: DC to 100 Hz
 - Environment: IP67 or better
 - Input Range: $\pm 2g$ - $\pm 6g$
 - B. Velocimeters
 - Minimum of three (3) components - Vertical, Longitudinal and Transverse
 - Natural frequency: Above 50 Hz.
 - Damping: Approximately 60 to 70 percent critical.
 - Sensitivity: ± 2 m/s
 - Bandwidth: 0.1 Hz to 100 Hz
 - Environment: IP67 or better
 - C. Data Logger / Recording. (Common for Accelerographs/Accelerometers and Velocimeters)
 - Sampling Frequency: A minimum of 100 samples per second.
 - Time: From at least 20 seconds before the ground shaking begins until 30 seconds after the last triggering level motion.
 - RMS Noise: System noise shall be less than $40 \mu g$'s measured over 0 – 30 Hz.
 - Media: Digital storage media (minimum of 32 GB)
 - D. Timing.
 - Interval: Half second or less.
 - Accuracy: Plus or minus 0.2 second per 100 seconds.
 - Type: GPS or NTP server.
 - E. Triggering.
 - Method: Pendulum or other device using earthquake motion as exciting force.
 - Level: Accelerograph: 0.5 to 100 gals, nominal / Velocimeter: 0.005 mm/s to 1 mm/s
 - Time: Full operation of accelerograph / velocimeter in not over 0.1 second after activation.
 - F. Power.
 - Battery maintained by trickle charger from AC power and capable of powering the accelerograph and velocimeter for two (2) days after loss of power.
 - G. Communication
 - Ethernet: 10 base-T or 100 base-TX
 - Protocol: TCP/IP FTP/SFTP
2. Records. When media is used for recording, a new media load shall be placed in the instruments when the media remaining is less than 1/3 of original load. For instruments, memory should be copied out and emptied when the remaining amount is less than 1/3 of the original capacity.
3. Refurbishing and Replacement. When the instrument supplier finds that the instrument must be removed from the building for repair, the instrument shall be replaced by a temporary identical instrument, and the permanent instrument shall be returned and made operative within 60 days from the removal date.

4. Battery Inspection. The instrument shall be tested with any charge device disconnected from an electric power source.

VIII. LOCATION AND INSTALLATION OF THE INSTRUMENTS

1. General.

The instrument shall be located so that access by qualified technical personnel is maintained at all times and is unobstructed by room contents. A sign stating "MAINTAIN CLEAR ACCESS TO THIS INSTRUMENT" shall be posted in a conspicuous location. *No instruments shall be located in refuge area.*

The preferred locations of the instruments are in small, seldom-used rooms or closets near a column (in a vertically aligned stack), with adequate space to securely mount the instrument and an approved protective enclosure attached securely to the floor. The locations shall be marked on the submitted structural and architectural floor plans, and properly approved.

2. Buildings with three (3) or more instruments.

Buildings with three (3) or more accelerographs/accelerometers shall be located in the ground floor/lowest basement, middle floor, and the topmost floor of the building. When applicable, velocimeter shall be located in the lowest basement or ground floor level. The locations of the instruments are selected to provide the maximum information of the building response from a major earthquake. Such information would form part of the valuable data in understanding the building's behavior during major seismic event.

3. Orientation of the Instruments.

All instruments shall be installed with the same orientation relative to the building, with the orientation chosen such that the reference or long dimension of the instrument is aligned with a major axis of the building. The orientation of the instrument shall be clearly marked on the submitted structural plans. The supplier-installer shall certify that the instruments are oriented as per plan.

IX. DATA RETRIEVAL AND INTERPRETATION

Immediately after the occurrence of an Intensity VI earthquake or greater in the locality as determined by the Philippine Institute of Volcanology and Seismology (PHIVOLCS), the Building Official shall issue a written notice to the building owner to retrieve the data and to have the data interpreted by an Accredited Structural Engineer. The retrieval and interpretation of the data shall be performed by an Accredited Structural Engineer. The data and interpretation of the building shall be submitted by the Owner to the DPWH for storage, post-earthquake safety evaluation of the building, and for emergency response.

X. DATA STORAGE AND ARCHIVING

Data storage and archiving shall be at the DPWH Central Office or other data centers designated by the DPWH. The ASEP, upon written request to the DPWH, shall be provided the said data.

XI. CERTIFICATE OF INSTALLATION OF EARTHQUAKE RECORDING INSTRUMENTATION

Upon compliance of building owners of these Guidelines and Implementing Rules on Earthquake Recording Instrumentation, the Building Official shall issue a Certificate of Installation of Earthquake Recording Instrumentation. The Certificate must be posted at the room/s where the instrument is located and in a conspicuous place, properly protected/secured, in the ground floor lobby of the building.

XII. TESTING, INSPECTION AND COMMISSIONING

Building Owner, Building Official, and Supplier shall inspect, test, and commission the seismic monitoring system together to ensure that the systems are in proper operational condition and comply with the requirements of these guidelines. The Supplier must submit a certificate from the manufacturer that the instrument is in good working condition.

The Building Owner shall be responsible for the protection and maintenance of the site of the ERI as prescribed in these guidelines.

XIII. SUPPORT AND MAINTENANCE

The seismic monitoring system shall have a maintenance clearance as per the requirement of the National Structural Code of the Philippines under Section 105.2. "Maintenance and service shall be provided by the owner of the building."

"The supplier shall provide guarantee that the system shall have a maintenance period for at least 10 years. For the service period, the maximum service interval is one year. The equipment obsolescence shall not hinder the proper continuous operation of the equipment throughout the 10 years duration. When the equipment's supplier finds that the instrument must be removed from the building for repair, there must be a service unit as a temporary replacement to continue the collection of data, if and when there is an occurrence of an earthquake during the duration of the repair.

XIV. REFERENCES

1. D Skolniket. al. *A Quantitative Basis for Building Instrumentation Specifications*, NSF CMMI Research and Innovation Conference, 2009 (Hawaii).
2. M. Celebi. *Seismic Instrumentation of Buildings: Special GSA/USGS PROJECT (2002)*.
3. *Guideline for ANSS Seismic Monitoring of Engineered Civil Systems – Version 1.0*.
4. *National Building Code of the Philippines, PD 1096*.
5. *National Structural Code of the Philippines (NSCP), Volume I, Buildings, Towers and Other Vertical Structures, Sixth Edition, 2010*.